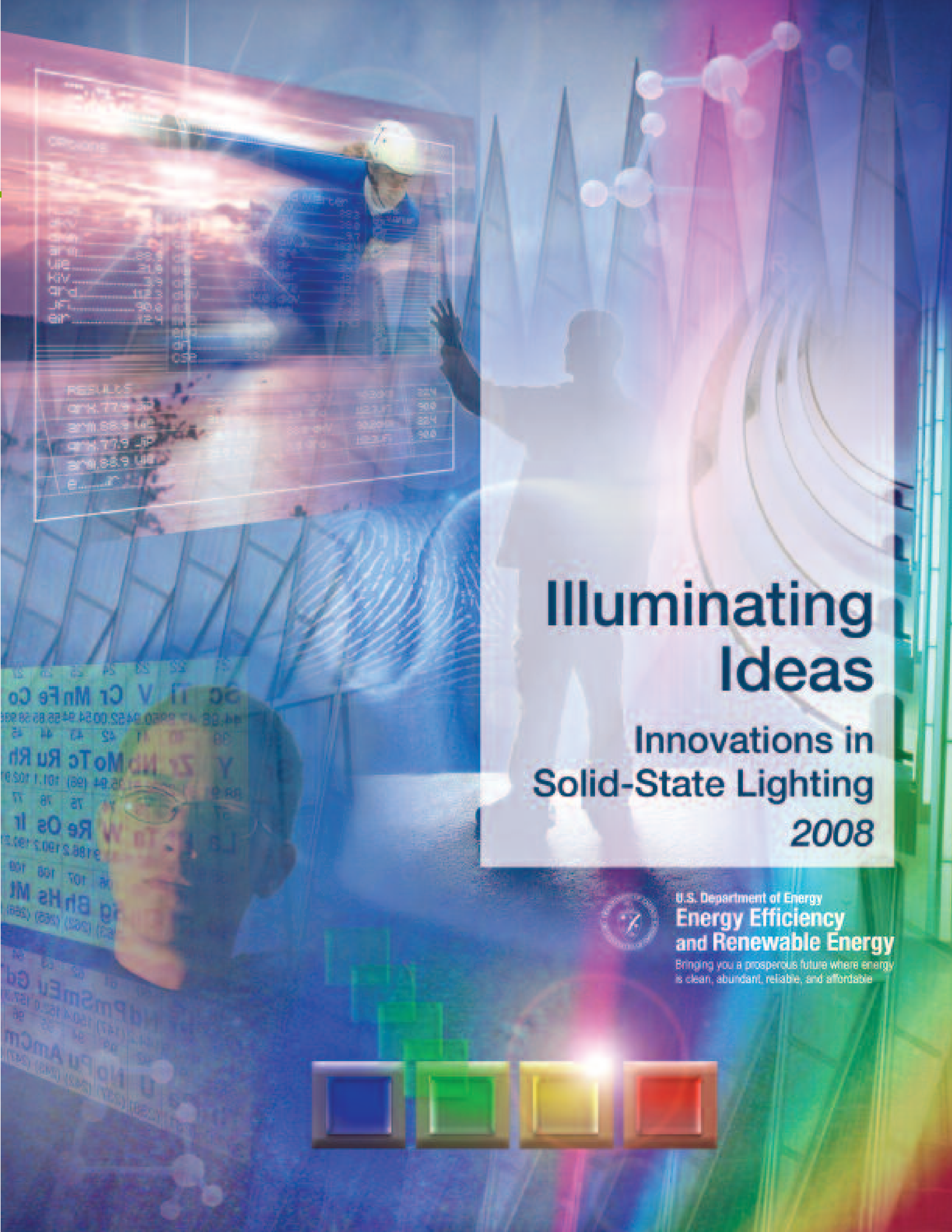


Illuminating Ideas

Innovations in Solid-State Lighting

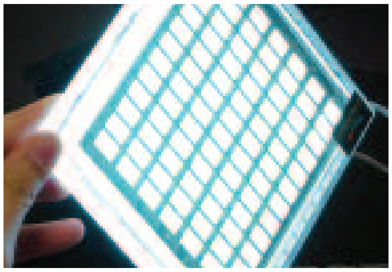
2008

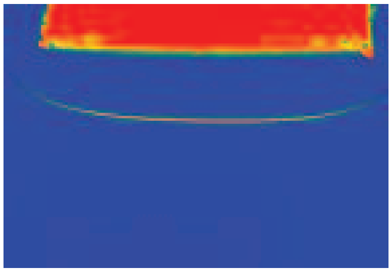
U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Lighting the Way to Energy Savings

Solid-state lighting is a pivotal emerging technology that promises to fundamentally alter and improve lighting systems – and buildings – of the future. No other lighting technology offers our nation so much potential to conserve electricity, at a time when our nation needs bold solutions to achieve greater energy independence.

Major research challenges must be addressed before the full promise of solid-state lighting is realized. In partnership with industry, research and academic organizations, and national laboratories, the U.S. Department of Energy is working to accelerate technology advances that will profoundly change the future of lighting. These collaborative, cost-shared efforts will ultimately deliver substantial energy savings for all lighting users and position U.S. companies for technology leadership in global markets for new products, systems, and services.





Photos provided by (left to right): Universal Display Corporation; Philips Solid-State Lighting Solutions; Sandia National Laboratory

Catalyzing Developments in Solid-State Lighting

Solid-state lighting (SSL) technologies today are undergoing rapid change and improvements, and high performance products for general illumination are already emerging on the market. The U.S. Department of Energy (DOE) is leading research efforts to achieve the full energy-saving potential of SSL, investing in projects that target needed improvements to ramp up efficiency and performance while driving down technology costs.

DOE support acts as a catalyst for the creation of SSL partnerships, driving toward development of highly efficient, full-spectrum, white-light SSL sources that will ultimately replace incandescent and fluorescent lamps used for general illumination.

Through a series of interactive workshops, DOE and its SSL partners have developed an extensive research agenda targeting technology improvements in light emitting diodes (LEDs) and organic light emitting diodes (OLEDs). These ongoing workshops provide an interactive forum to ensure that DOE funds the appropriate research topics to accelerate development of efficient, full-spectrum, white-light SSL sources.

DOE-funded researchers strive for technology advances and efficiency breakthroughs that will make SSL a cost-effective, energy-saving alternative for general lighting applications. The following project results from 2007 highlight major breakthroughs and represent important steps toward DOE's long-term research goals.

Cree, Inc. has demonstrated a cool white multi-chip LED component prototype with efficacies of 88-95 lm/W at 350 mA. The LED component consumes approximately 8 watts. This demonstration is based on Cree's EZBright™ chip technology platform combined with prototype packaging technology.

Philips Solid-State Lighting Solutions has collaborated with Cree to develop an LED PAR lamp that produces 54 lm/W, which is significantly more efficient than comparable LED PAR 38 lamps on the market, and 4-5 times more efficient than incandescent PAR 38 lamps. This new hybrid-LED source incorporates advanced LED package and system integration technology plus novel, highly efficient driver technology and a unique optical arrangement.

The National Renewable Energy Laboratory and Pacific Northwest National Laboratory have teamed to demonstrate OLEDs that use a robust transparent conducting oxide (TCO) based on gallium doped ZnO, instead of more costly indium tin oxide (ITO). This breakthrough achievement reveals the potential for a new generation of designable TCO materials with enhanced performance at reduced cost.

Universal Display Corporation has demonstrated an all-phosphorescent white OLED with an efficacy of 45 lm/W at 1,000 cd/m2, with a color rendering index of 78. This achievement was enabled by lowering the operating voltage, increasing the outcoupling efficiency, and incorporating highly efficient phosphorescent emitters.

These research teams continue to strive for further technology improvements, working to develop higher efficiency SSL technologies that compete in the general illumination market and deliver significant energy savings.

Sample Projects

The following projects initiated in 2007 provide a sampling of some key areas of focus. For more information on each project, see the DOE SSL Project Portfolio at www.netl.doe.gov/ssl.

Carnegie Mellon University and University of Michigan: Novel Heterostructure Designs for GaN-Based LEDs

Energy losses in GaN-based LEDs are known to occur (1) at contacts; (2) in the n and p regions of the device; (3) in the active and quasi-neutral regions (non-radiative losses); and (4) in the active region due to uncaptured energy carriers. This research team will explore the mechanisms underlying these energy losses, gaining insight that could lead to the higher external efficiencies and the higher permissible current injection levels (current densities) needed to make these devices practical for consumer applications.

Cree, Inc.: LED Chips and Packaging for 120 lm/W SSL Component

Cree, Inc. is investigating LED chip and package efficiency improvements to create a novel soft white lamp module for insertion into high efficiency SSL luminaires. Advances in chip light extraction and white conversion technology are targeted to achieve, by the end of 2009, an overall efficiency gain of 43 percent compared to the baseline technology at the start of the project. These improvements will establish a scalable technology platform for manufacturing low-cost, high-efficiency commercial luminaire units. The goal is to produce 120 lm/W lamp modules that will emit at 4100K for integration into 1500 lumen luminaires.

GE Global Research, Massachusetts Institute of Technology, and Stanford University: High Quantum Efficiency OLED Lighting Systems

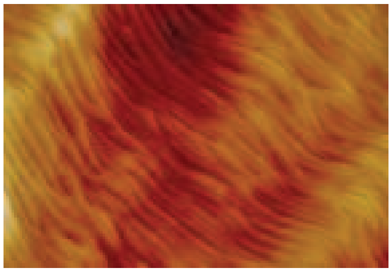
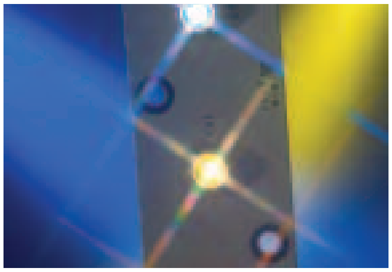
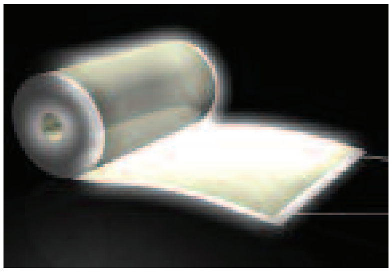
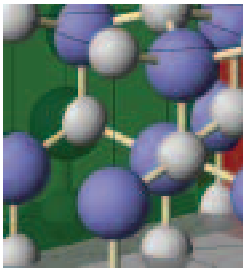
This team is working to construct high internal quantum efficiency OLEDs with optimal system performance on ultra-high barrier plastic substrates. To maximize OLED external efficiency, novel electron control and electrode modification schemes will be applied to GE solution-processed OLED designs, which in turn will maximize the output of the light-emitting elements when coupled to a light extraction architecture. The goal is to produce an illumination-quality white light source with a luminous output comparable to a standard 60W incandescent lamp (900 lm), but with an efficacy of more than 75 lm/W, an area less than 0.35m^2, and a lifetime greater than 7,000 hours.

Inlustra Technologies and the University of California, Santa Barbara: High-Efficiency Non-Polar GaN-Based LEDs

Conventional blue and green InGaN-based LEDs are produced by growing InGaN quantum wells on polar GaN crystal planes. The efficiency of these devices is limited by high built-in electric polarization fields, which distort quantum well energy band structures. By utilizing non-polar GaN crystal planes (such as the m-plane and a-plane) as well as advanced defect-reduction techniques, this team hopes to achieve higher internal quantum efficiency levels in blue and especially green InGaN-based high-brightness (HB) LEDs. When optimized, the researchers believe that these HB-LEDs will have peak luminous efficacies well in excess of the 2010 DOE laboratory target of 154 lm/W.

Pacific Northwest National Laboratory: High-Stability Organic Molecular Dopants for Maximum Power Efficiency OLEDs

Low voltage OLEDs have been demonstrated by doping transport layers with molecules that donate extra charge into the system. These "charge transfer" molecules tend to be volatile and can diffuse into the light-emitting region where they decrease device efficiency.

Investigators at PNNL hope to develop a new set of stable molecular dopants that can be deposited controllably using vacuum sublimation techniques. These molecular dopants consist of high-electron-affinity groups tethered to stable, vacuum-sublimable anchor molecules. In addition to improving the stability of doped OLEDs, the ability to control doping in fixed positions will create compositionally graded layers leading to optimization of both voltage and efficiency in bright, long-lived OLEDs.

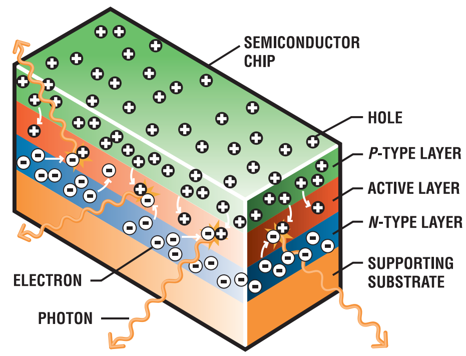
Physical Optics Corporation: Highly Efficient Organic Light-Emitting Devices for General Illumination
Following up on the successful demonstration of a prototype High-Efficiency OLED (HE-OLED) system in the first phase of this project, researchers at Physical Optics Corporation are trying to extend the use of their holographic Light Shaping Diffuser to new OLED substrates. These new substrates must have suitable encapsulated light scattering structures and be capable of mass production at low cost. When combined with the Light Shaping Diffuser, the substrates will enhance the light extraction efficiency and improve the uniformity of light output and color perception of OLEDs.

Sandia National Laboratory: Improved InGaN Epitaxial Quality by Optimizing Growth Chemistry
Researchers at SNL are trying to develop high-efficiency green (530 nm) light emitters by improving InGaN epitaxial material quality. The high indium compositions needed for green light emission in LEDs are difficult to obtain because limited thermodynamic stability and unwanted parasitic chemical reactions prevent controllable and efficient epitaxial InGaN growth. By systematically studying and controlling the incorporation of indium in LED active regions, the investigators are attempting to increase the internal quantum efficiency of InGaN. Enhanced control of indium incorporation will also enable better LED manufacturability.

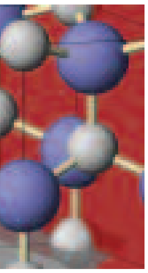
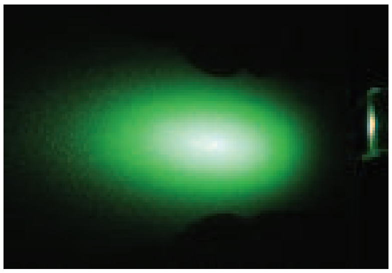
Universal Display Corporation: WOLEDs Containing Two Broad Emitters
UDC is continuing its efforts to simplify the architecture and to reduce manufacturing costs of white OLEDs by using only two emitters and/or as few organic materials as possible. To accomplish this, they use phosphorescent emitter technology to enhance the recombination efficiency of excitons within the emissive layer of a device. Their goal in this phase is to produce low-cost, high-efficiency, solid-state illumination sources with a color rendering index greater than 75, an efficacy of 60 lm/W and LT70 = 10,000 hours at 1,000 cd/m2.

Efficient Production of Light

When efficiency goals are met, SSL will produce light with less heat than any other source. At the heart of an SSL device is a sandwich of semi-conductor layers built on a substrate. Electrons released from the negative n-type layer combine with holes from the positive p-type layer. These electron-hole pairs recombine in the active layer to produce photons.



An LED is a very small (dot-sized) electrical device that produces light through the semi-conducting properties of its metal alloys. An OLED is a surface-shaped device, similar to an LED, composed of small molecules or polymers that emit light.

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A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

To Participate in DOE Solid-State Lighting R&D

Does your company, research organization, or university have a promising solid-state lighting technology that will save energy? If so, your research and development efforts may be eligible for funding of up to 80 percent. To learn more, visit **www.netl.doe.gov/ssl**

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